Jet vetoes and resummation

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Snowmass Energy Frontier Workshop 2013

based on works by
Banfi, Salam and Zanderighi '12, Banfi, Monni, Salam and Zanderighi '12,
Becher and Neubert '12, Rothen, Becher and Neubert '13,
Tackmann, Walsh and Zuberi '12, Stewart, Tackmann, Walsh and Zuberi '13,
XL and Petriello '12, XL and Petriello '13,

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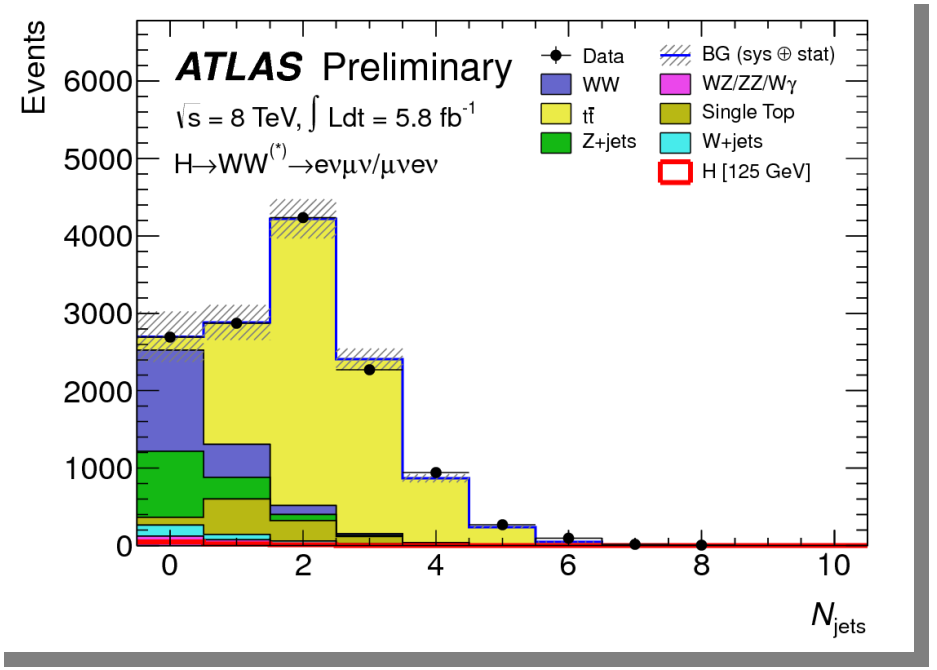
Outline

- Motivation and theory issues
- Progress
  - Higgs+0j
  - Higgs+1j
- Summary

Theory issues

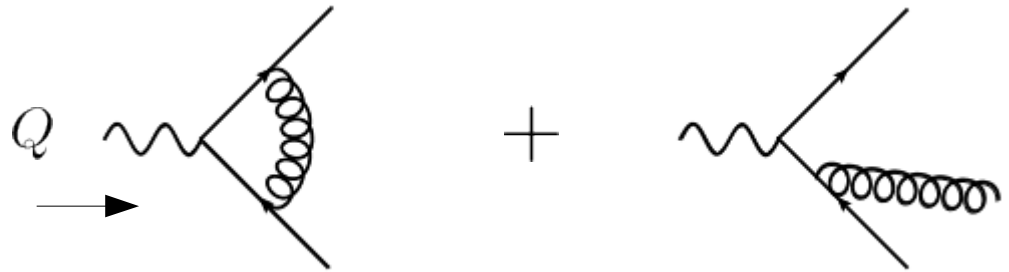
- Jet bin cross section
  - Beat the backgrounds
    - Use 25-30 GeV jet cut, restrict QCD activity

$$p_T^{veto} \sim 25\mathrm{GeV} \ll Q \sim m_H \sim 125\mathrm{GeV}$$

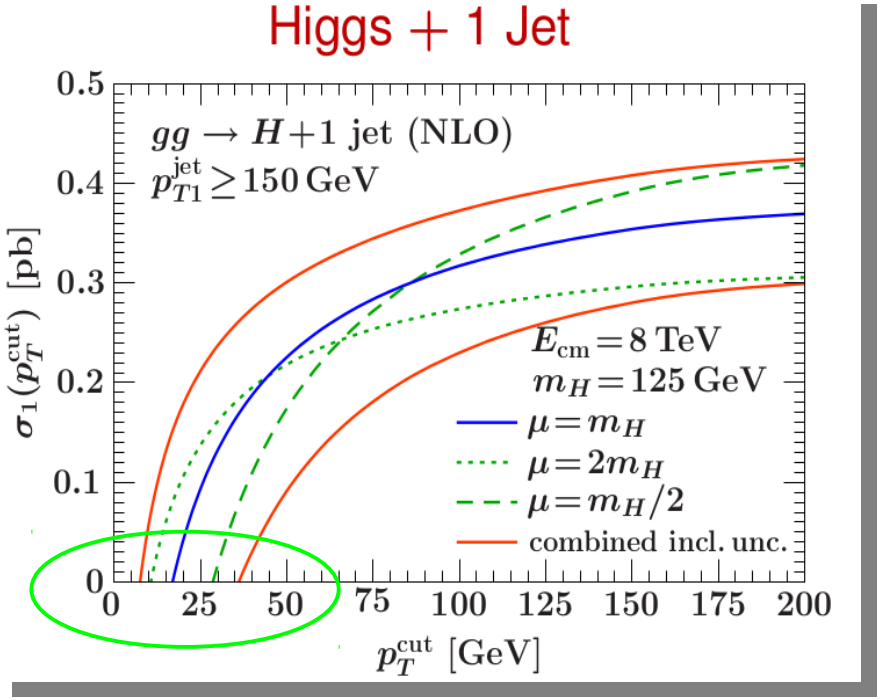


Theory issues

- Jet bin cross section
  - Theoretical issues
    - Fixed order breaks down
      - Jet veto logs



$$\propto -\frac{1}{\epsilon_{\rm IR}^2} - \frac{1}{\epsilon_{\rm IR}} \qquad \propto \frac{1}{\epsilon_{\rm IR}^2} + \frac{1}{\epsilon_{\rm IR}} + \log^2\frac{p_T^{veto}}{Q} + \log\frac{p_T^{veto}}{Q}$$



Stewart and Tackmann '11

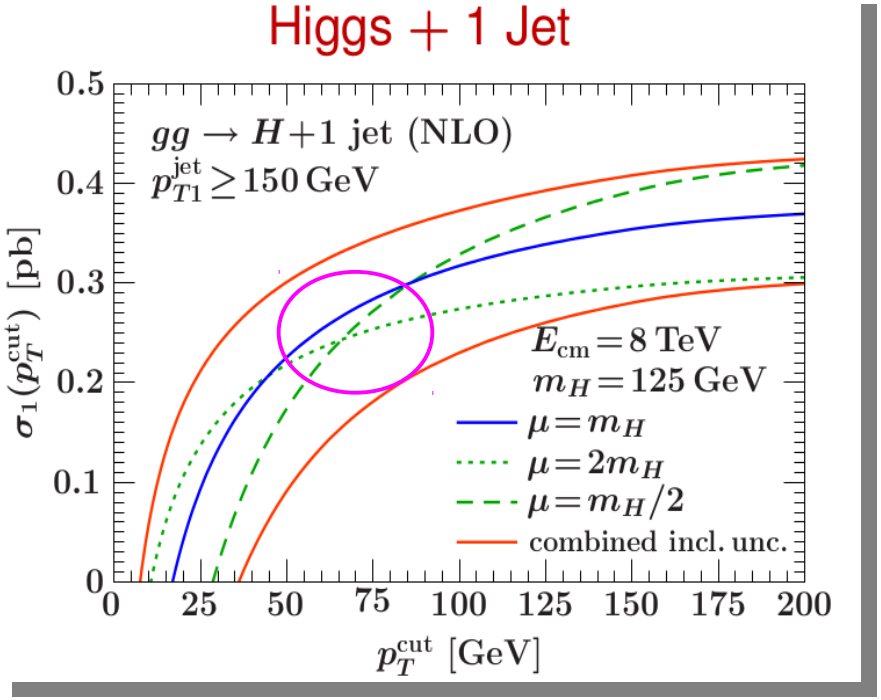
Theory issues

- Jet bin cross section
  - Theoretical issues
    - Fixed order breaks down
    - Unreliable uncertainty

$$\sigma_{=1j}(p_{T1}^J, p_{\rm cut}) = \sigma^{\geq 1j}(p_{T1}^J) - \sigma^{\geq 2j}(p_{T1}^J, p_{T2}^J > p_{\rm cut})$$

$$\sigma^{\geq 1j}_{p_{T1}^J \geq 120{\rm GeV}} = (0.31{\rm pb})\left[1 + 2.9\alpha_s + \mathcal{O}(\alpha_s^2)\right]$$

$$\sigma^{\geq 2j}_{p_{T1}^J \geq 120{\rm GeV}, p_{T2}^J \geq 60{\rm GeV}} = (0.31{\rm pb})\left[3.7\alpha_s + \mathcal{O}(\alpha_s^2)\right]$$



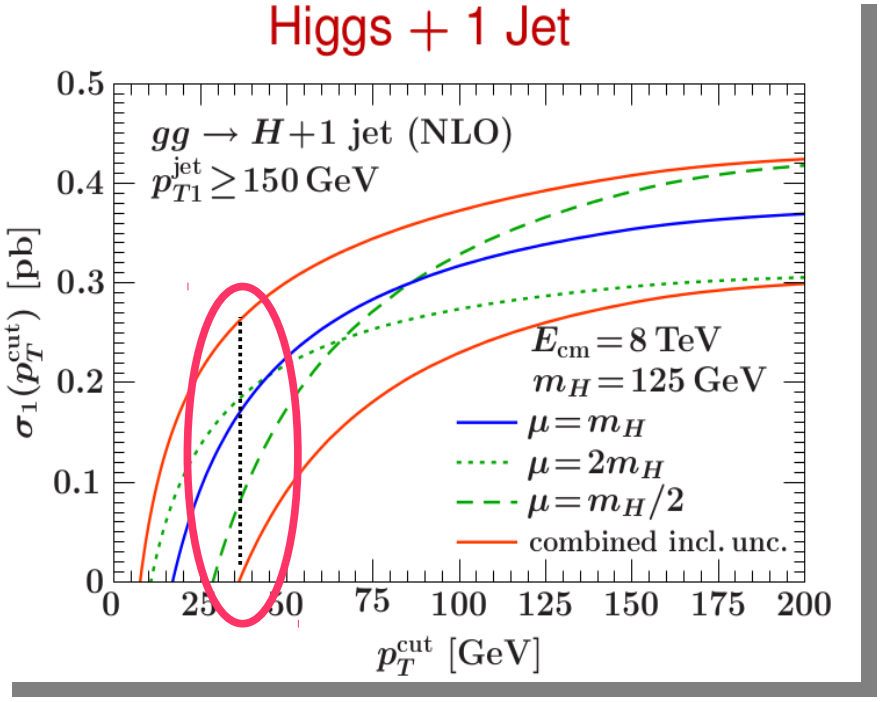
Accidental cancellation between large virtual corrections and logarithms leads to reduced scale errors. Does not necessarily persist to all orders

Theory issues

- Jet bin cross section
  - Theoretical issues
    - Fixed order breaks down
    - Unreliable uncertainty
    - ST prescription (Stewart and Tackmann '11)
      - Large theoretical errors

Fixed order uncertainty:

$$\delta_{1j}^2 = \delta_{>1j}^2 + \delta_{>\ 2j}^2$$

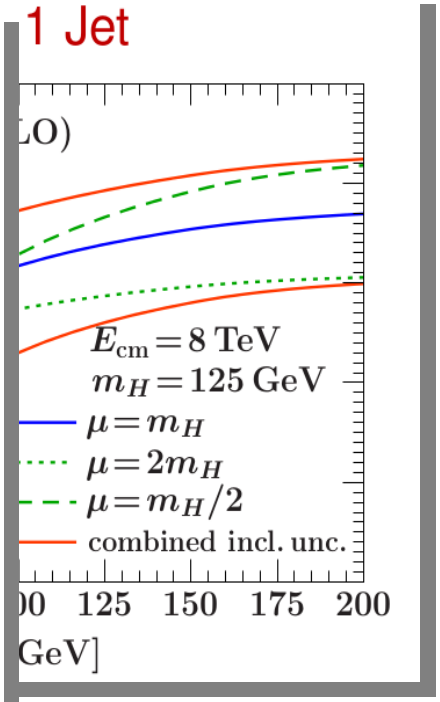


Theory issues

- Jet bin cross section
  - Theoretic
    - Fixed or
    - Unreliab
    - ST pres
      - Large

fix o

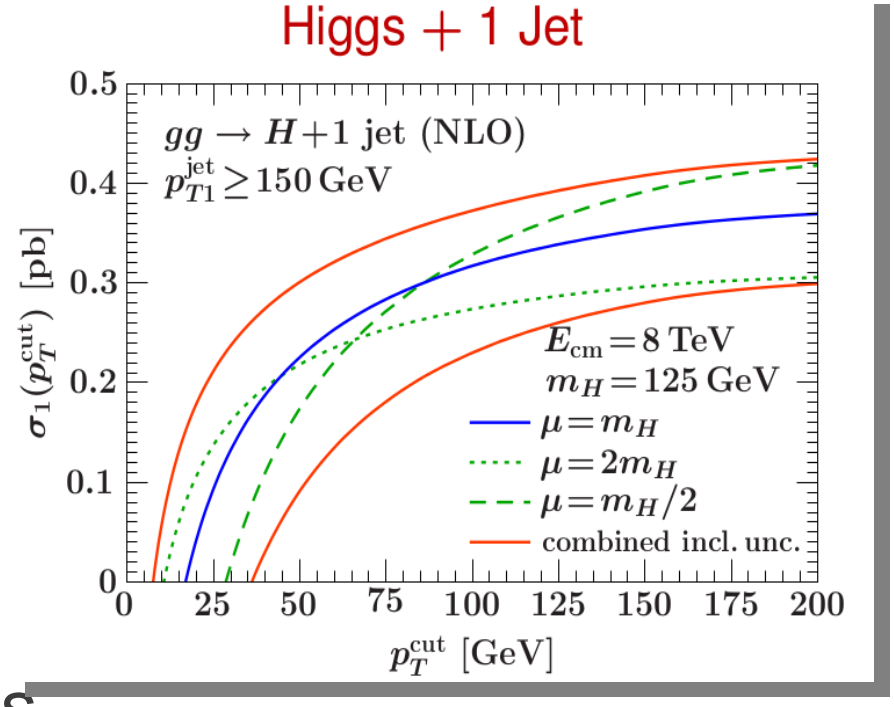
Source (0-jet)	Signal (%)	Bkg. (%)
Inclusive ggF signal ren./fact. scale	13	-
1-jet incl. ggF signal ren./fact. scale	10	-
PDF model (signal only)	8	-
QCD scale (acceptance)	4	-
Jet energy scale and resolution	4	2
W+jets fake factor	-	5
WW theoretical model	-	5
Source (1-jet)	**Signal (%)**	**Bkg. (%)**
1-jet incl. ggF signal ren./fact. scale	26	-
2-jet incl. ggF signal ren./fact. scale	15	-
Parton shower/ U.E. model (signal only)	10	-
b-tagging efficiency	-	11
PDF model (signal only)	7	-
QCD scale (acceptance)	4	2
Jet energy scale and resolution	1	3
W+jets fake factor	-	5
WW theoretical model	-	3



Higgs Measurement: Theoretical errors dominate over the other uncertainty sources

Theory issues

- Jet bin cross section
  - Theoretical issues
    - Fixed order breaks down
    - Unreliable uncertainty
    - ST prescription (Stewart and Tackmann '11)
      - Large theoretical errors
  - Have to sum up jet veto logs
    - Improve accuracy systematically
    - Reliable error estimations



Not only for Higgs
Also true
for Z,W or NP and etc.

Progress

- Significant recent efforts in resummation
  - H+0j through NNLL'+NNLO (jettiness) Berger, et al '11
  - H+0j through NNLL'+NNLO (kt type) refs. see upcoming slides
  - H+1j through NLL'+NLO (anti-kt) refs. see upcoming slides
- Log counting

$$\sigma_{\rm resum} = \sigma_{\rm tree}(1+\alpha_s C_1+\alpha_s^2 C_2+\cdots)\exp\left[Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \cdots\right]$$

$Lg_1(\alpha_s L) \to \alpha_s^n L^{n+1}$, $g_2(\alpha_s L) \to \alpha_s^n L^n$, $\alpha_s g_3(\alpha_s L) \to \alpha_s^n L^{n-1}$

$LL : Lg_1(\alpha_s L)$

$NLL : Lg_1(\alpha_s L) + g_2(\alpha_s L)$

Parton Shower : LL + fine tuning

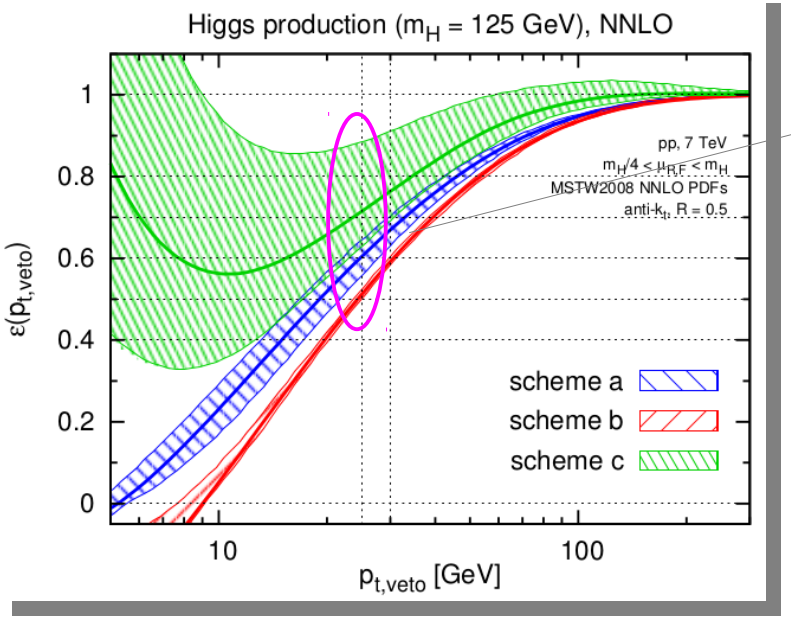
$NNL' : \alpha_s C_1, Lg_1(\alpha_s L) + g_2(\alpha_s L)$

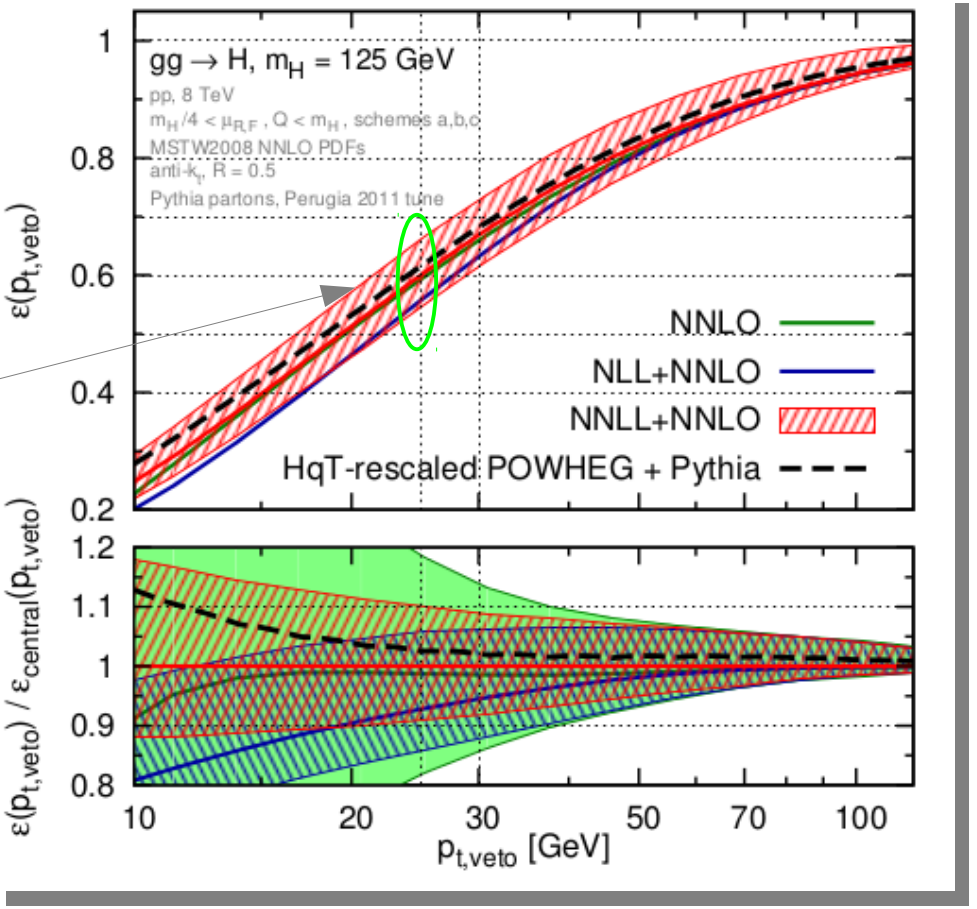
$NNLL : \alpha_s C_1, Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L)$

$NNLL' : \alpha_s C_1 + \alpha_s^2 C_2, Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L)$

Progress

- Numerical consequence
  - Higgs + 0j
    - NNLL+NNLO





$$\epsilon(p_{t,veto}) = \frac{\sigma_{0j}}{\sigma_{\text{inclu.}}}$$

Banfi, Monni, Salam and Zanderighi, '12

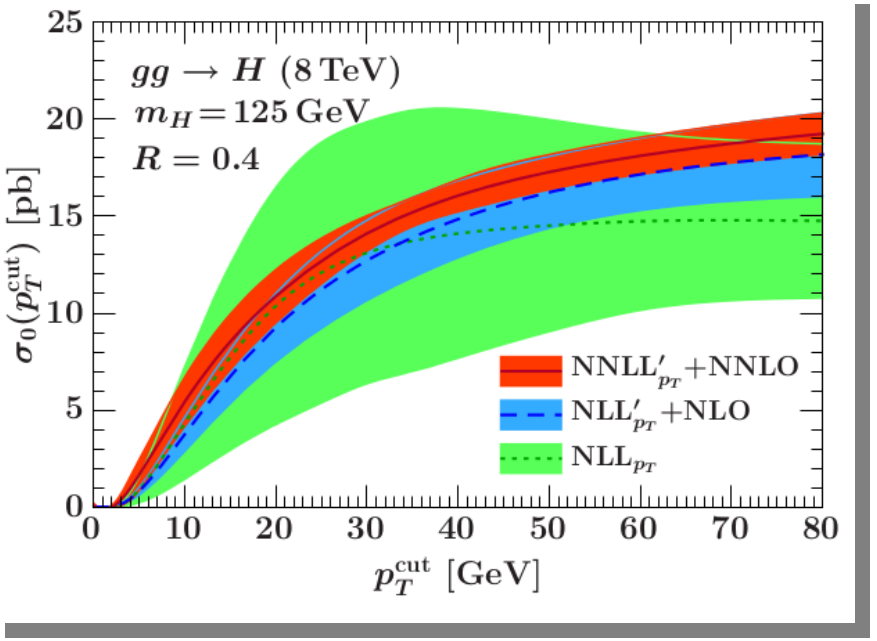
$$NNLL : \alpha_s C_1, Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L)$$

Progress

- Numerical consequence
  - Higgs + 0j

PRELIMINARY

    - NNLL'+NNLO
      - Uncertainties from a new scale in EFT Chiu, Jain, Neill, Rothstein '12
      - Profile scales



Stewart, Tackmann, Walsh, and Zuberi '13
Results from Tackmann's talk at SCET workshop 2013

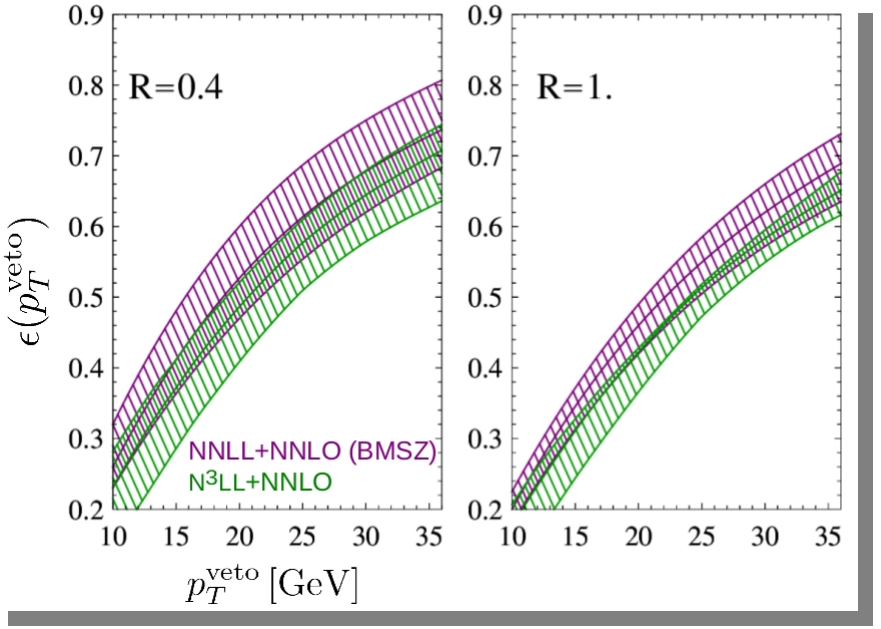
$$NNLL' : \alpha_s C_1 + \alpha_s^2 C_2, Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L)$$

Progress

- Numerical consequence
  - Higgs + 0j

PRELIMINARY

    - Even beyond
      - Missing log(R) term for N3LL, but estimated to be small

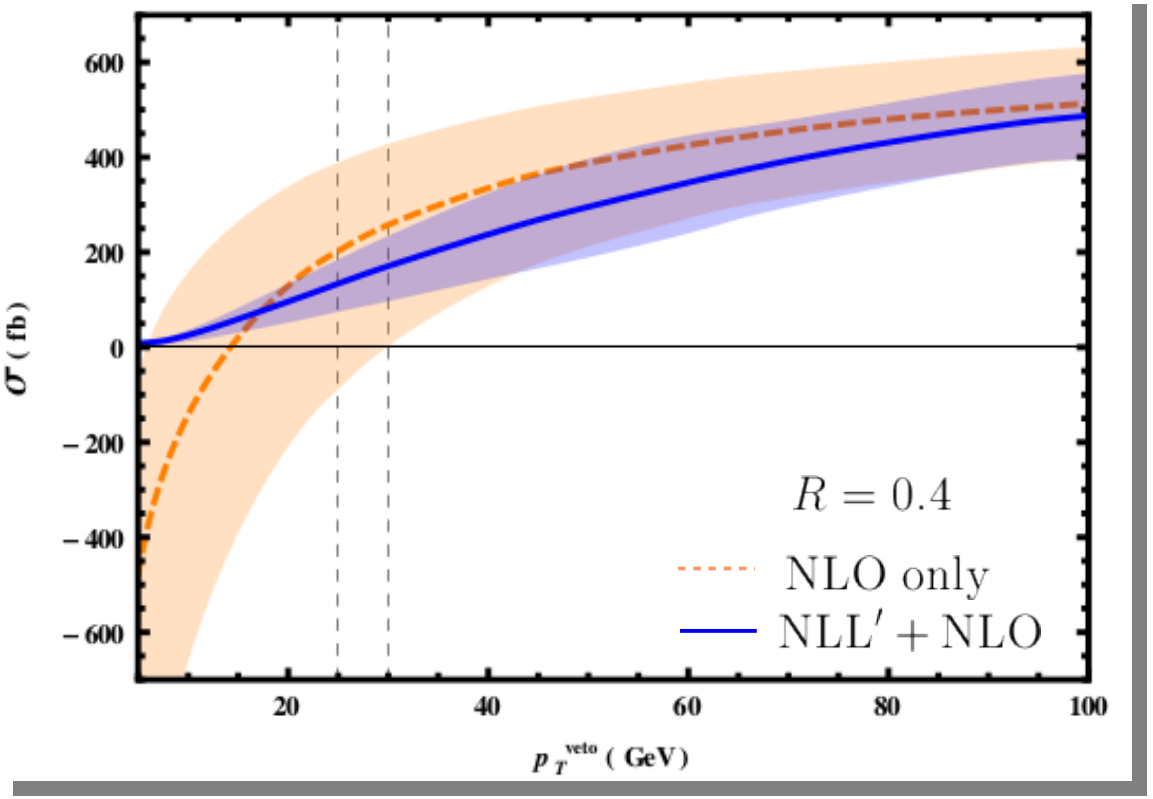


Becher, Neubert '12
Rothen, Becher and Neubert '13
Results from Rothen's talk at SCET workshop 2013

$$NNNLL: \alpha_s C_1 + \alpha_s^2 C_2, L g_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \alpha_s^2 g_4(\alpha_s L)$$

Progress

- Numerical consequence
  - Higgs + 1j
    - High ptj > 120GeV
      - Conservative error estimation



XL and Petriello'12, XL and Petriello'13

$$NNL' : \alpha_s C_1, Lg_1(\alpha_s L) + g_2(\alpha_s L)$$

Progress

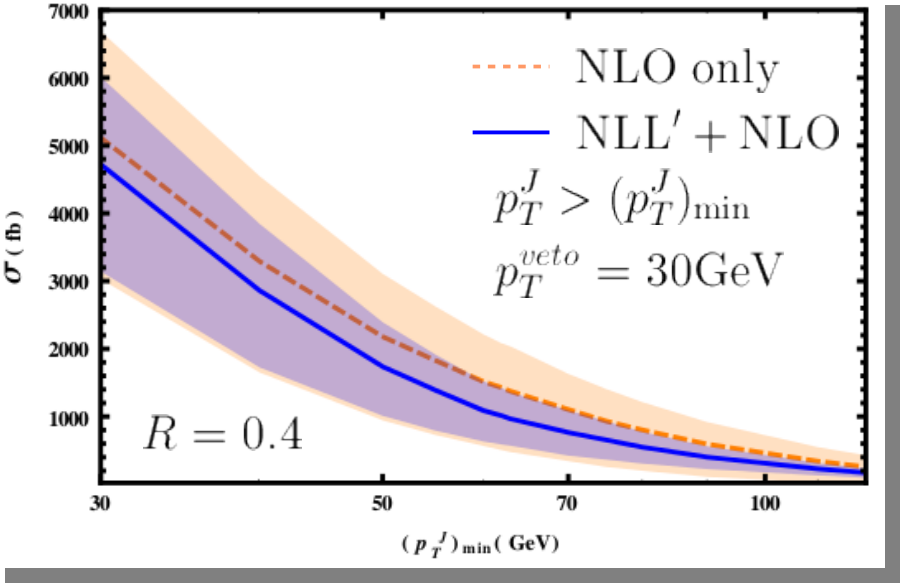
- Numerical consequence
  - Higgs + 1j
    - Entire Spectrum
      - Non-negligible contributions from high ptj region
      - Large uncertainty driven by the errors in high ptj region
      - Our formalism can be used to greatly reduce the errors

NLO:	$\sigma(p_T^J > 30)(\mathrm{pb})$	$\sigma(63 > p_T^J > 30)(\mathrm{pb})$	$\sigma(p_T^J > 63)(\mathrm{pb})$
$\mu = m_H/2$	$5.2^{+1.65}_{-2.12}$	$3.9^{+1.01}_{-0.95}$	$1.3^{+0.75}_{-1.30}$

XL and Petriello'12, XL and Petriello'13

Progress

- Numerical consequence
  - Higgs + 1j
    - Entire Spectrum
      - Conservative error estimation
      - Up to 25% reduction in the uncertainty



m_H (GeV)	p_T^{veto} (GeV)	σ_{NLO} (pb)	$\sigma_{\mathrm{NLL}'+\mathrm{NLO}}$ (pb)	f^{1j}_{NLO}	$f^{1j}_{\mathrm{NLL}'+\mathrm{NLO}}$
124	25	$5.92^{+35\%}_{-46\%}$	$5.62^{+29\%}_{-30\%}$	$0.299^{+38\%}_{-49\%}$	$0.283^{+33\%}_{-34\%}$
125	25	$5.85^{+34\%}_{-46\%}$	$5.55^{+29\%}_{-30\%}$	$0.300^{+37\%}_{-49\%}$	$0.284^{+33\%}_{-33\%}$
126	25	$5.75^{+35\%}_{-46\%}$	$5.47^{+30\%}_{-30\%}$	$0.300^{+38\%}_{-49\%}$	$0.284^{+34\%}_{-33\%}$
124	30	$5.25^{+31\%}_{-41\%}$	$4.83^{+29\%}_{-29\%}$	$0.265^{+35\%}_{-43\%}$	$0.244^{+33\%}_{-33\%}$
125	30	$5.19^{+32\%}_{-41\%}$	$4.77^{+30\%}_{-29\%}$	$0.266^{+35\%}_{-43\%}$	$0.244^{+33\%}_{-33\%}$
126	30	$5.12^{+32\%}_{-41\%}$	$4.72^{+30\%}_{-29\%}$	$0.266^{+35\%}_{-43\%}$	$0.246^{+33\%}_{-32\%}$

XL and Petriello'12, XL and Petriello'13

Extra comment

- Non-global logs for H+1j XL and Petriello'13
  - Occurs only in high ptj region starting at NLL'
  - Can be resummed in large Nc limit Dasgupta and Salam'13
  - Contribute roughly 3% to high ptj region at NLL'
  - Contribute around 0.1% to the total cross section

Summary

- Formalism to understanding jet bin cross section has been established (not only Higgs)
- More reliable prediction and reduced theory uncertainty
- Error estimation should be revised using the resummed results for higgs + 0j and higgs +1j
- Fine tuning work worth probing (higher accuracy, log(R) issue, non-global logs, etc..)

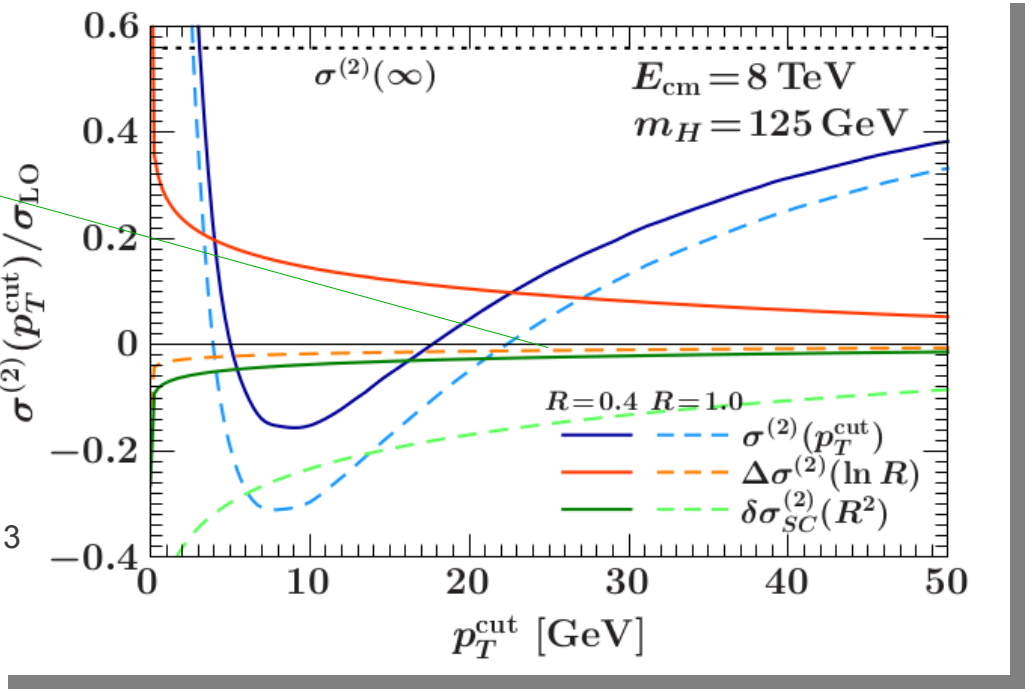
Thanks

Backup

- Soft and beam mixing
  - Small R~0.4
  - Large R~1. (in debate)
    - Power suppressed
      - If one does calculations consistently

PRELIMINARY

see Rothen's talk at SCET workshop 2013



Tackmann, Walsh, Zuberi'12

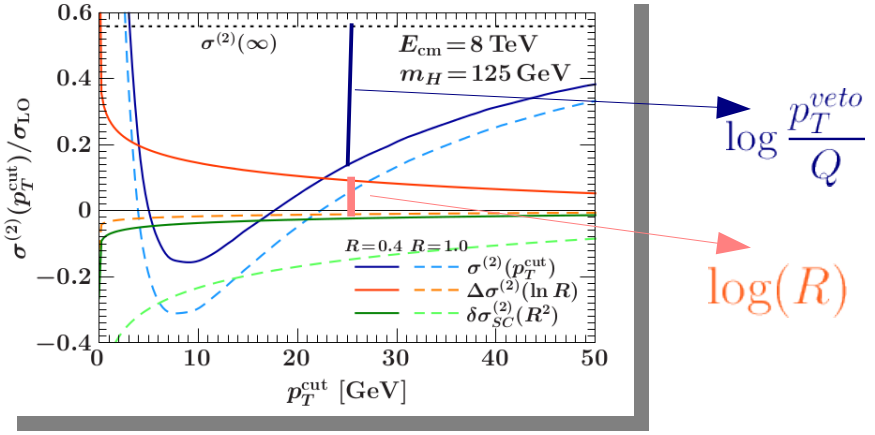
Backup

- Log(R) effect

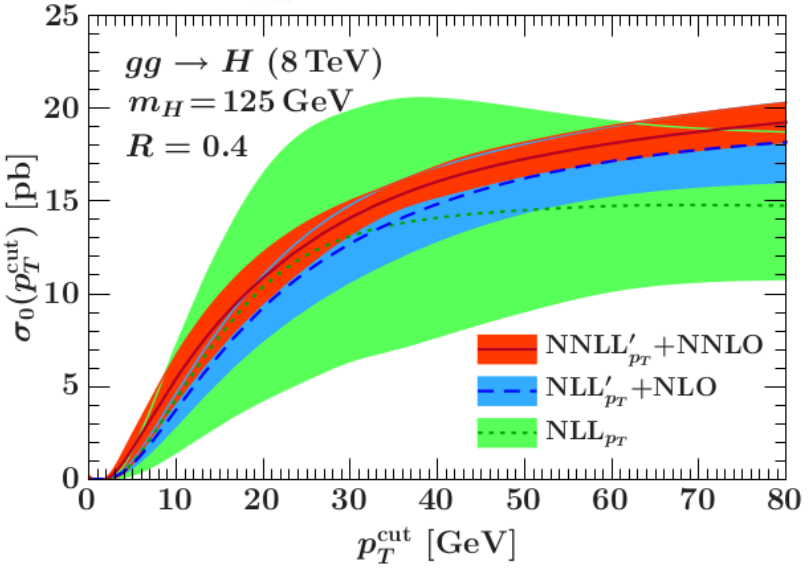
$$\Delta\sigma(0.4, 25\,\text{GeV})/\sigma_B = \{14\%, 3.6\%, 0.9\%, \ldots\}$$
$$\Delta\sigma(0.7, 25\,\text{GeV})/\sigma_B = \{5.5\%, 0.55\%, 0.05\%, \ldots\}$$

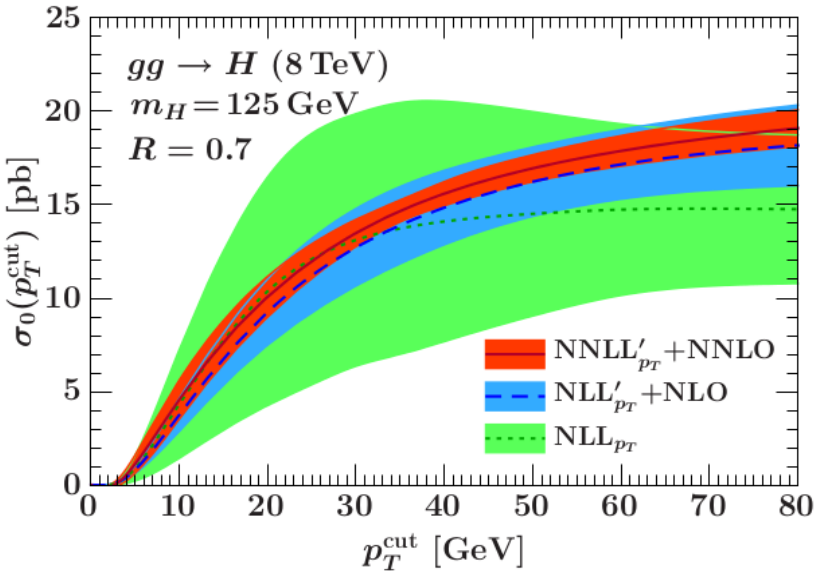
PRELIMINARY

Estimated higher order Log(R) contributions



Tackmann, Walsh, Zuberi '12





Stewart, Tackmann, Walsh, and Zuberi '13
Results from Tackmann's talk at SCET workshop 2013